Electronic Depiction of Instrument Approach Procedure (IAP) Charts

Phase I: Development and Preliminary Evaluation

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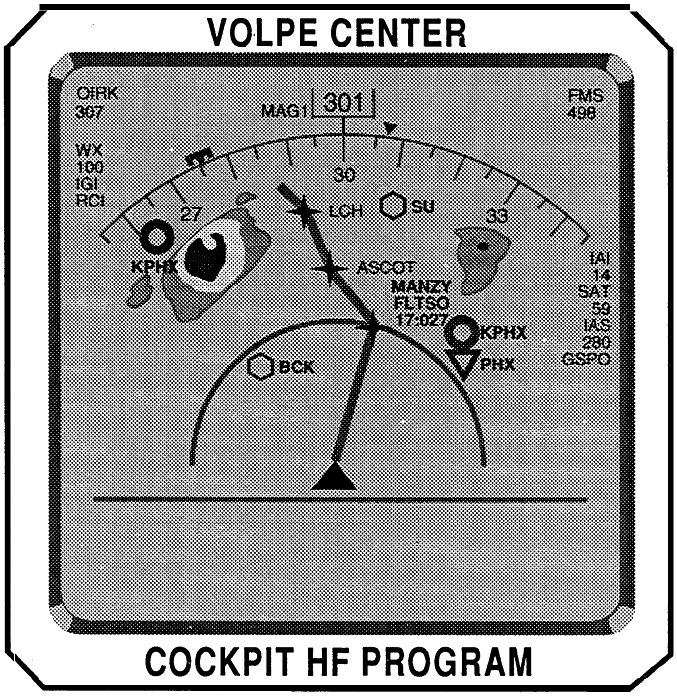
Washington, DC 20591



Daniel J. Hannon
M. Stephen Huntley, Jr.

U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

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1.1.1 Location in the Cockpit

The location of the display in the cockpit is an important issue in the design of electronic displays of aeronautical charts. Paper charts are typically held in front of the-pilot in a clip on the yoke, in the pilot's hand, or on the lap. The pilot is free to move the chart to any desired location in order to maximize the lighting conditions for viewing the chart. An electronic display most likely will be mounted in a fixed position in the cockpit. Pilots will have to change their scan patterns to incorporate the information on the electronic display. Additionally, the ambient lighting may not always be optimal for viewing this display device and some conditions may make the display impossible to read (e.g., when the display is under direct sunlight). Display technologies differ with respect to viewing angle, brightness, contrast, and sunlight reflection. The location of the display device in the cockpit, therefore, will be a critical consideration for the installation of any electronic charting display and will vary with the type of the display. The parameters that define the envelope of safe locations for cockpit installation will have to be determined for each display technology.

The fixed distance of electronic display screens from the pilot in the cockpit imposes minimum size requirements for text and symbols. Currently, the pilot is free to move paper charts as close as needed for viewing small symbols and text. However, the range of text sizes and symbols on paper charts does not allow for quick interpretation at distances greater than arm's length. Therefore, a minimum size must be established for text and symbols on electronic displays which will be even farther away in the cockpit than paper charts. This issue will also have an impact on chart design.

1.1.2 Display Size

Current paper charts come in a variety of sizes, with the smallest being single-sheet IAP charts, and the largest being fold-out enroute charts. Cockpit electronic displays will be of fixed size and, due to the limited amount of space available on most cockpit instrument panels, will likely be smaller than even the current IAP charts. The transfer of information from paper charts of varied size to an electronic display of fixed size poses several questions to the electronic chart designer including, for example:

- How much of the current information on paper charts needs to be transferred to the electronic screen?
- How much of a given chart needs to be seen at one time?
- How quickly does a pilot need to be able to see new information?

The minimum portion of information that is needed by the pilot for electronic depiction of aeronautical charts, from the set of information that is presently shown on paper aeronautical charts, will have to be determined. Given the considerations of display size stated above, alternative chart designs will have to be developed and evaluated on electronic display

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configurations of information. Criteria must be developed to guide designers in the creation of displays that pilots can interpret quickly.

1.2 RECENT RESEARCH ON THE ELECTRONIC DEPICTION OF AERONAUTICAL CHARTS

1.2.1 Information Requirements

Interest is growing in determining the information requirements of pilots using aeronautical charts in order to optimize electronic chart formats. The phase of flight requiring the greatest amount of information access, the IAP, has received the most attention. Hofer et. al. (1992) and Ricks et al. (1994) attempted to determine the information required of pilots during an IAP and to categorize that information meaningfully. Zirkler and Morton (1990) developed an engineering model to determine the information requirements of paper IAP charts and a hypermedia-based display. Clay (1993) determined the cognitive components of flying IAPs. These studies concluded that the information needs of the pilot during an instrument approach change with the phase of flight and vary from pilot to pilot. It is not likely, therefore, that an automated system will be optimized for all pilots, or that every pilot will need all of the enhancements to aeronautical charts that electronic depiction will provide.

1.2.2 Empirical Studies

Mykityshyn, Kuchar, and Hansman (1994) measured information retrieval from several electronic display formats and from conventional IAP paper charts. The electronic formats offered pilots a "decluttering" mechanism that reduced the amount of information presented to them from the content on the paper charts. Based on their own preferences, pilots were able to configure the decluttering mechanism. Faster response times were obtained to probe questions for a color-coded, decluttered moving map display than for conventional paper charts. Pilots did not perform better with a monochrome electronic displays than with paper charts. These authors also reported strong pilot preference for color coding of information and for a north-up orientation of the plan view map.

Hofer et al. (1992) and Hofer (1993) found similar results to the study above. Faster information retrieval times were obtained for decluttered electronic IAP displays than for paper charts. Pilots preferred the north-up orientation electronic display with a moving airplane symbol on both plan and profile views to a track-up electronic display and conventional paper charts.

In all three of these empirical studies, decluttered electronic display designs were preferred by pilots. These results indicated that all of the information contained on current paper IAP charts was not always needed to fly instrument approaches. The cleaner appearance of decluttered electronic charts compared to paper charts is a clear advantage for electronic displays. However, what information may be eliminated safely from a chart at the pilot's

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2.4 DISPLAY SCREEN CONFIGURATION

The display screen can be arranged in any configuration desired. Currently, design prototypes have utilized two dimensional maps, such as the plan and profile views on IAP charts. The size of the maps is variable, and the scale displayed within the maps is also adjustable. Sections of the display can be dedicated to text displays, graphic displays, or a combination. Touch-sensitive buttons also have been presented as a user interface. Dynamic information can be displayed anywhere on the screen. The flexibility available in screen configuration allows for testing multiple display formats.

The relative advantages of map displays over tabular information display is an issue currently under examination. Future plans include consideration of map size on navigation performance. Figure 2 presents an illustration of one of the prototype electronic charts that have been created.

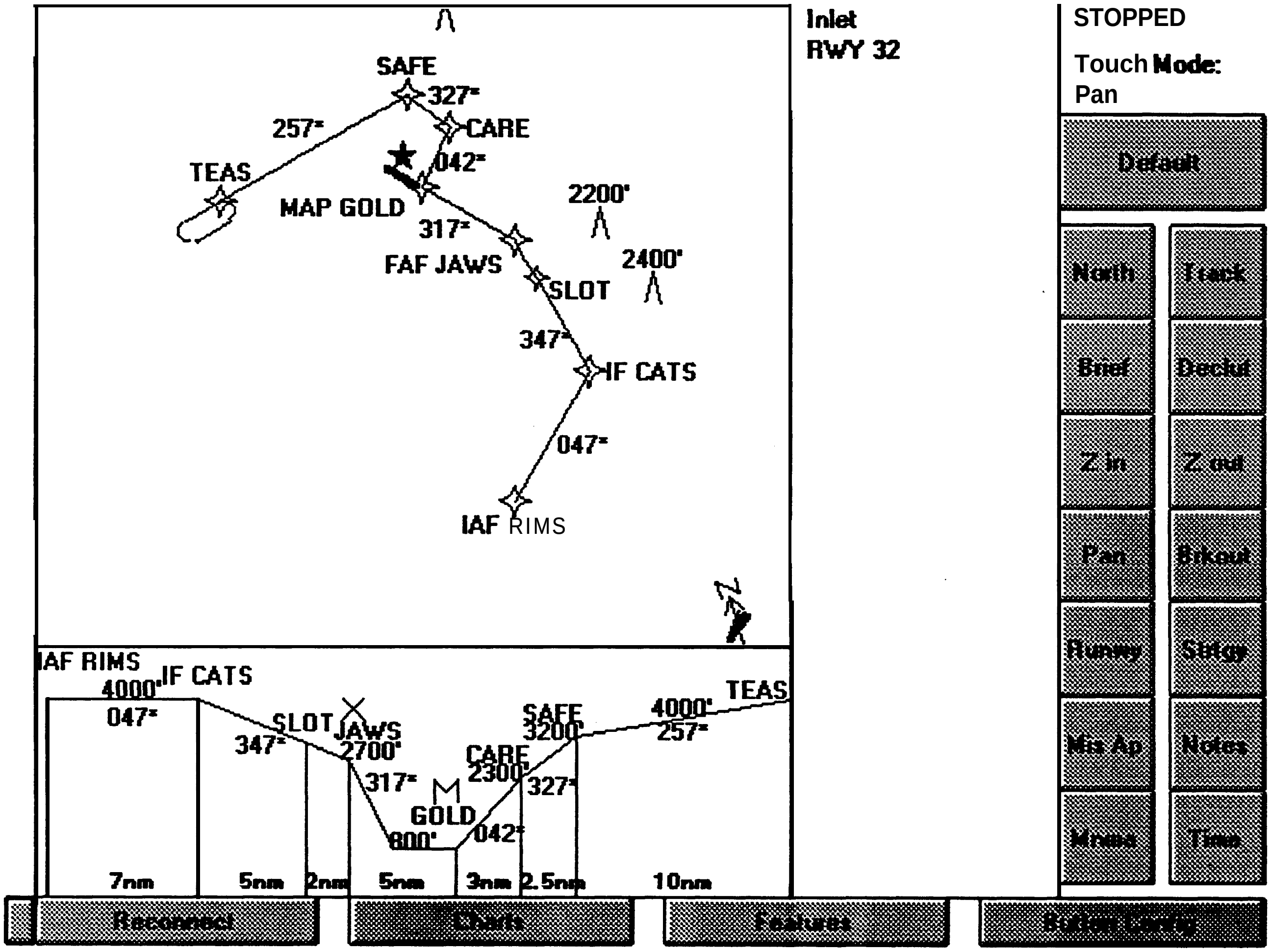

Figure 2. An illustration of a display design using the electronic charting tools at VNTSC. Plan and profile view maps provide static and dynamic information. Text information is presented in the center column. The right area of the screen is dedicated to a touch-sensitive interface.

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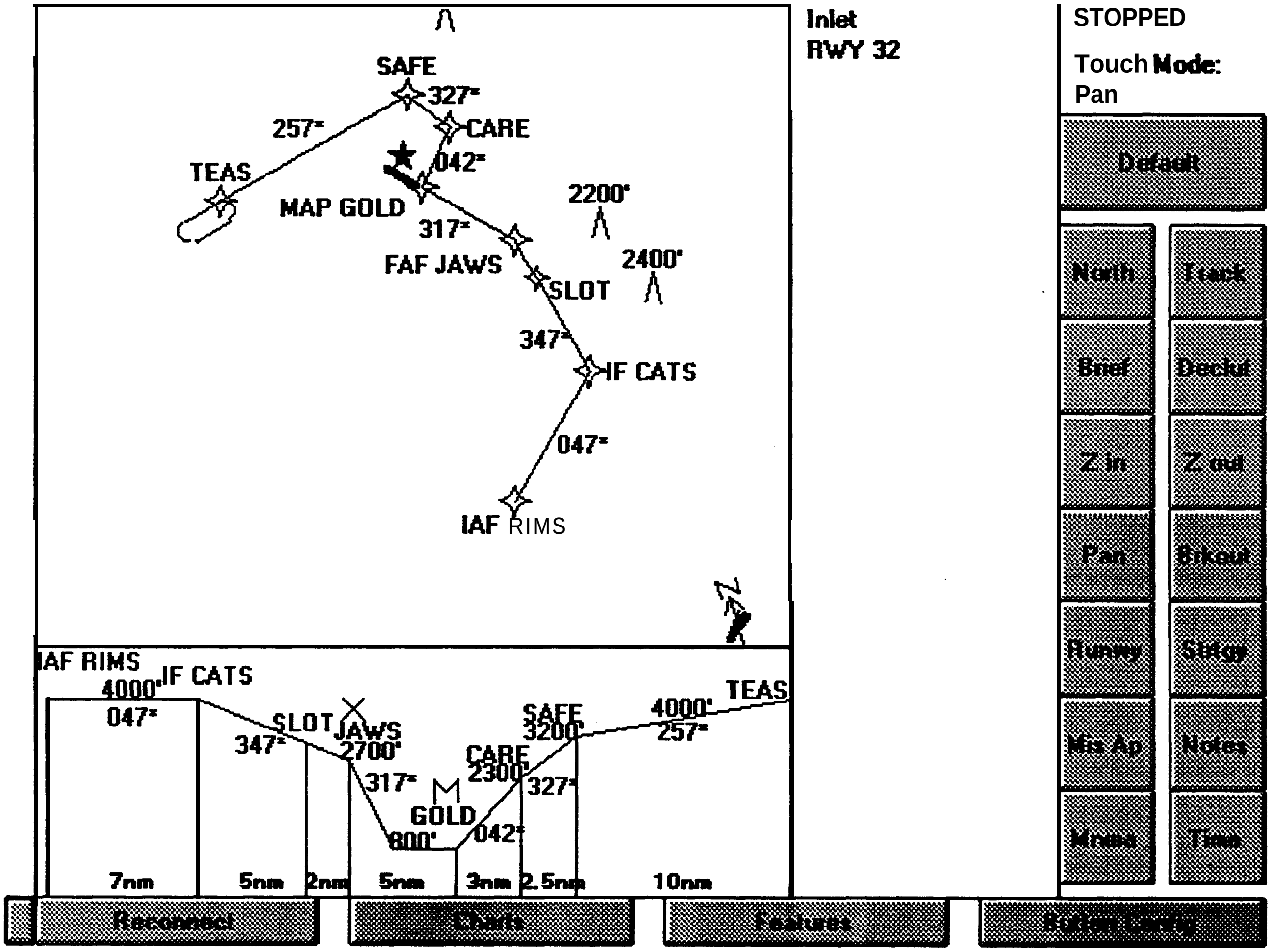

Figure 2. An illustration of a display design using the electronic charting tools at VNTSC. Plan and profile view maps provide static and dynamic information. Text information is presented in the center column. The right area of the screen is dedicated to a touch-sensitive interface.

Current paper charts vary the kinds of information displayed, e.g., detailed runway maps may be shown on one set of pages and an instrument approach chart and a break-out' chart of the runway lighting system on another. This display system also has a page overlay feature that allows for the use of multiple pages of information. A smaller overlay window has been created to provide information from a briefing strip. One alternative to overlaying information is to dedicate an area on the screen for changing information. A separate area has been designated for providing the missed approach instructions, minima, notes, and remaining text or graphic information (e.g., missed approach icons). This information is available at the push of a button. Another area has been designated for providing communication and navaid frequencies. These methods of presentation of information may have a direct impact on pilot use and interpretation of the system. The flexibility designed into this display tool allows for testing a variety of presentation techniques.

2.7 INTERFACE AND AUTOMATION

All of the features built into the current display system are not needed at the same time. Selecting among the options requires a user interface. The choice of interface is another important area that must be addressed in the design of electronic charting systems. Guidelines exist for the creation of intuitive interfaces. However, these have primarily come from office environment studies and may not be practical for the cockpit. In time critical situations, a pilot may not be able to interact with a system designed for less stressful working conditions. This display system tool will allow for addressing the impact of interface design on pilot performance during stressful situations.

Automating functions provides one approach to the simplification of user interfaces. For example, communication frequencies can be selectively displayed so that only those that are needed at the moment or for the next phase of flight can be displayed. It also may be possible for the system to automatically tune the radios. Frequencies that are not in use can be stored in computer memory and displayed when needed. This feature would likely reduce display clutter and pilot confusion about radio frequencies. Automation, therefore, potentially reduces the pilot's need to interact with the system and can help the pilot think ahead.

Negative aspects of automation, however, limit what can be accomplished. Automation tends to make the system operator complacent and less situationally aware. Creating a system that can handle or anticipate all situations or that can be overridden in situations it is not equipped to handle is very difficult. The balance between user interface and automation must be explored for electronic chart systems. This balance may change according to the level of pilot and crew experience and type of aircraft. This research tool will promote an empirical evaluation of automation on pilot performance.

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Two performance measures and two subjective measures were collected during the study. The first performance measure was the pilot's flight performance. Cross-track error (XTE), airspeed, and altitude were recorded on each approach. The second performance measure was a light perimeter side-task in which pilots had to use a button on the yoke to-extinguish one of four lights spaced across the instrument panel of the simulator. The lights came on, one at a time, at random times, during the approach. After fourteen seconds, a light timed out if it was not extinguished by the pilot. Response latency and accuracy were recorded. This task was designed to measure the spare attention of the pilot while flying and to detect any differences in scan pattern over the flight instruments related to the different displays. Similar tasks have been used to measure changes in spare attention (e.g., Huntley, 1973). The two subjective measures included a ten-point subjective scale of mental workload (Bedford Scale) and a post-flight questionnaire, rating each of the display formats.

Pilots flew a total of eight GPS instrument approaches, two using each of the electronic display formats and two using a paper IAP chart, depicting a GPS approach. (All eight are presented in Appendix B.) The paper charts were similar in content to the electronic displays. All of the charts were relatively uncluttered. Each approach was constructed for the study and flown into fictitious airports. All approaches were designed within FAA-Terminal Instrument Procedures (TERPS) criteria. To increase the challenge of the simulation, a moderate level of turbulence was added along with cross winds. Additionally, the missed approach procedures (MAP) were also made particularly challenging on the last approach flown using each format.

As described above, each display was designed to evaluate particular aspects of the issues involved in the design of electronic IAP charts. It was anticipated that:

- Little difference would be found between the dependent measures for the first electronic format and paper chart conditions.

- The second format, with the dynamic information, would allow for more spare attention as measured by the perimeter side-task and would be preferred by pilots to all other formats.

- Flight performance for the third format would be comparable to the paper chart condition, but spare attention might be less as measured by the perimeter side-task, mental workload higher, and subjective ratings worse than by using the paper chart.

- Systematic differences in instrument scan pattern for the different display formats would be revealed by the perimeter side-task.

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- Systematic differences in instrument scan pattern for the different display formats would be revealed by the perimeter side-task.

Two performance measures and two subjective measures were collected during the study. The first performance measure was the pilot's flight performance. Cross-track error (XTE), airspeed, and altitude were recorded on each approach. The second performance measure was a light perimeter side-task in which pilots had to use a button on the yoke to-extinguish one of four lights spaced across the instrument panel of the simulator. The lights came on, one at a time, at random times, during the approach. After fourteen seconds, a light timed out if it was not extinguished by the pilot. Response latency and accuracy were recorded. This task was designed to measure the spare attention of the pilot while flying and to detect any differences in scan pattern over the flight instruments related to the different displays. Similar tasks have been used to measure changes in spare attention (e.g., Huntley, 1973). The two subjective measures included a ten-point subjective scale of mental workload (Bedford Scale) and a post-flight questionnaire, rating each of the display formats.

Pilots flew a total of eight GPS instrument approaches, two using each of the electronic display formats and two using a paper IAP chart, depicting a GPS approach. (All eight are presented in Appendix B.) The paper charts were similar in content to the electronic displays. All of the charts were relatively uncluttered. Each approach was constructed for the study and flown into fictitious airports. All approaches were designed within FAA-Terminal Instrument Procedures (TERPS) criteria. To increase the challenge of the simulation, a moderate level of turbulence was added along with cross winds. Additionally, the missed approach procedures (MAP) were also made particularly challenging on the last approach flown using each format.

As described above, each display was designed to evaluate particular aspects of the issues involved in the design of electronic IAP charts. It was anticipated that:

- Little difference would be found between the dependent measures for the first electronic format and paper chart conditions.

- The second format, with the dynamic information, would allow for more spare attention as measured by the perimeter side-task and would be preferred by pilots to all other formats.

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Table 1. Flight performance, perimeter, and workload results

	Format 1 (static)	Format 2 (dynamic)	Format 3 (text only)	Paper
XTE (miles)Final	0.132	0.094	0.116	0.157
XTE (miles)Missed	0.632	0.536	0.377	0.428
Response Latency (sec)	4.56	4.59	4.94	5.0.
Response Accuracy (%)	55	49	59	49
Mental Workload	4.6.	4.2.	5.6	5.6

The response latency and percent correct data shown in Table 1 are averaged for the four light positions on the instrument panel. Response latency to all three electronic displays was slightly shorter than to the paper condition. Accuracy was highest for format three (text only), with format two (dynamic) and paper having equally low accuracy results. Response latency as a function of the different light positions is plotted in Figure 4 for the different display formats.' There are no systematic variations for the different display conditions between the four light positions. In general, response latency to the right two lights was faster than the left two and more closely grouped, with the fastest times overall recorded for the second light position.

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4. FUTURE DIRECTIONS

The suggestions we have received from pilots on the electronic chart displays that we have developed, in addition to our empirical findings and the general human factors issues noted above, have led to the creation of new electronic chart designs. Three prototype displays are currently being tested and fine-tuned and will receive empirical evaluation in the future. A description of each of the new electronic chart design concepts is discussed below.

4.1 DYNAMIC TEXT

One of the most interesting findings in this study is that the third display format, using only a tabular display of IAP information, resulted in acceptable flight performance in the simulator. This format was developed, in part, to explore the necessity of using maps for presenting procedural information. The table was static, that is, all of the information was continuously present and did not change during the flight. In general, pilots commented that this third format provided an unambiguous interpretation of the instrument approach and missed approach procedures. Although this format used a smaller display screen area than either of the two formats that used maps, the alphanumerics were fairly large and pilots rated this type of display as very easy to read. Several pilots, however, commented that the organization of the display was potentially confusing. During the approach it was difficult to remember what line to read in the table. It also was confusing to have the numeric data following the name of the waypoint. With the waypoint name first in the row, some pilots initially thought the quantitative information applied to the leg of the approach following the waypoint (i.e., from the waypoint). A new table design was created to address these limitations (see Figure 7).

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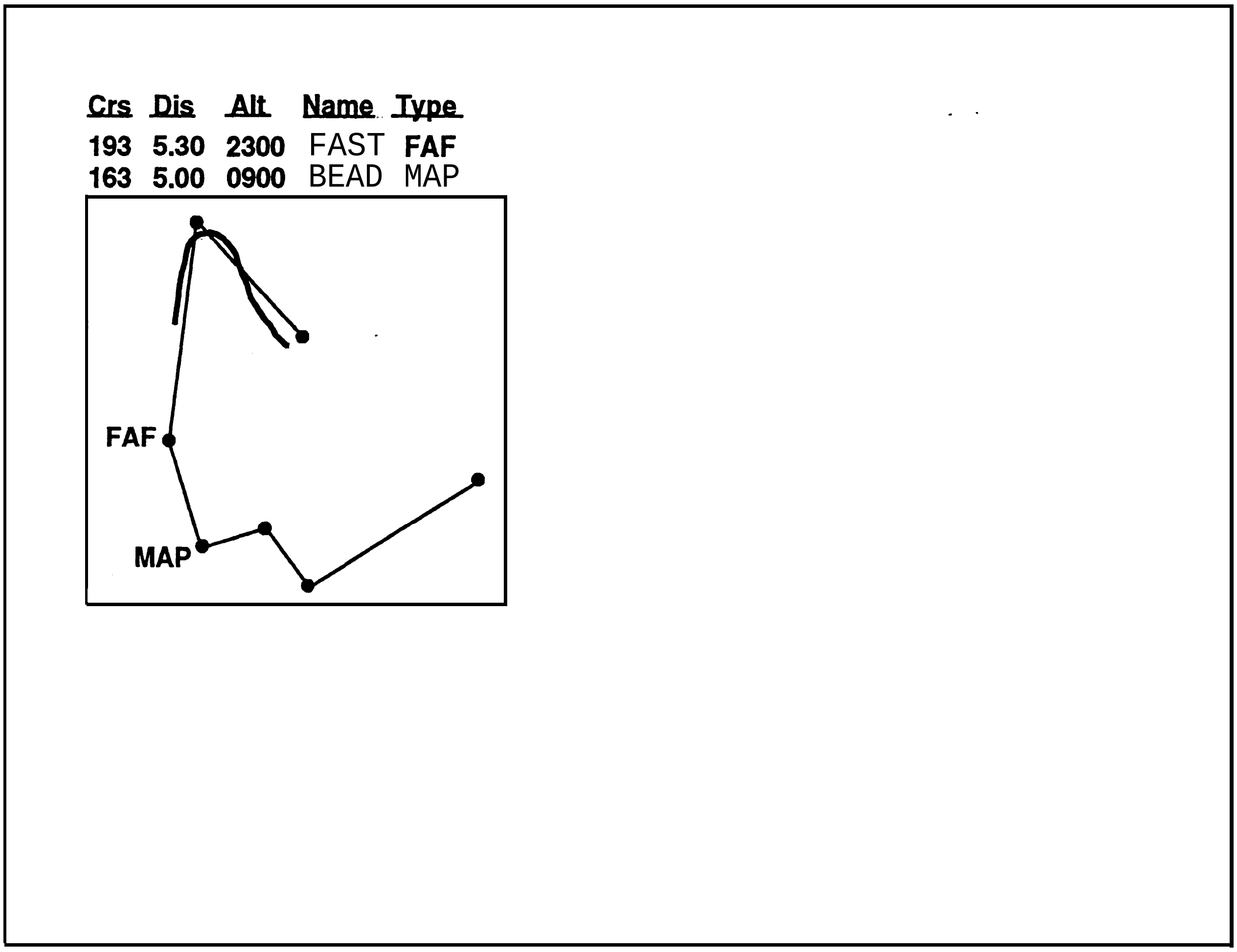
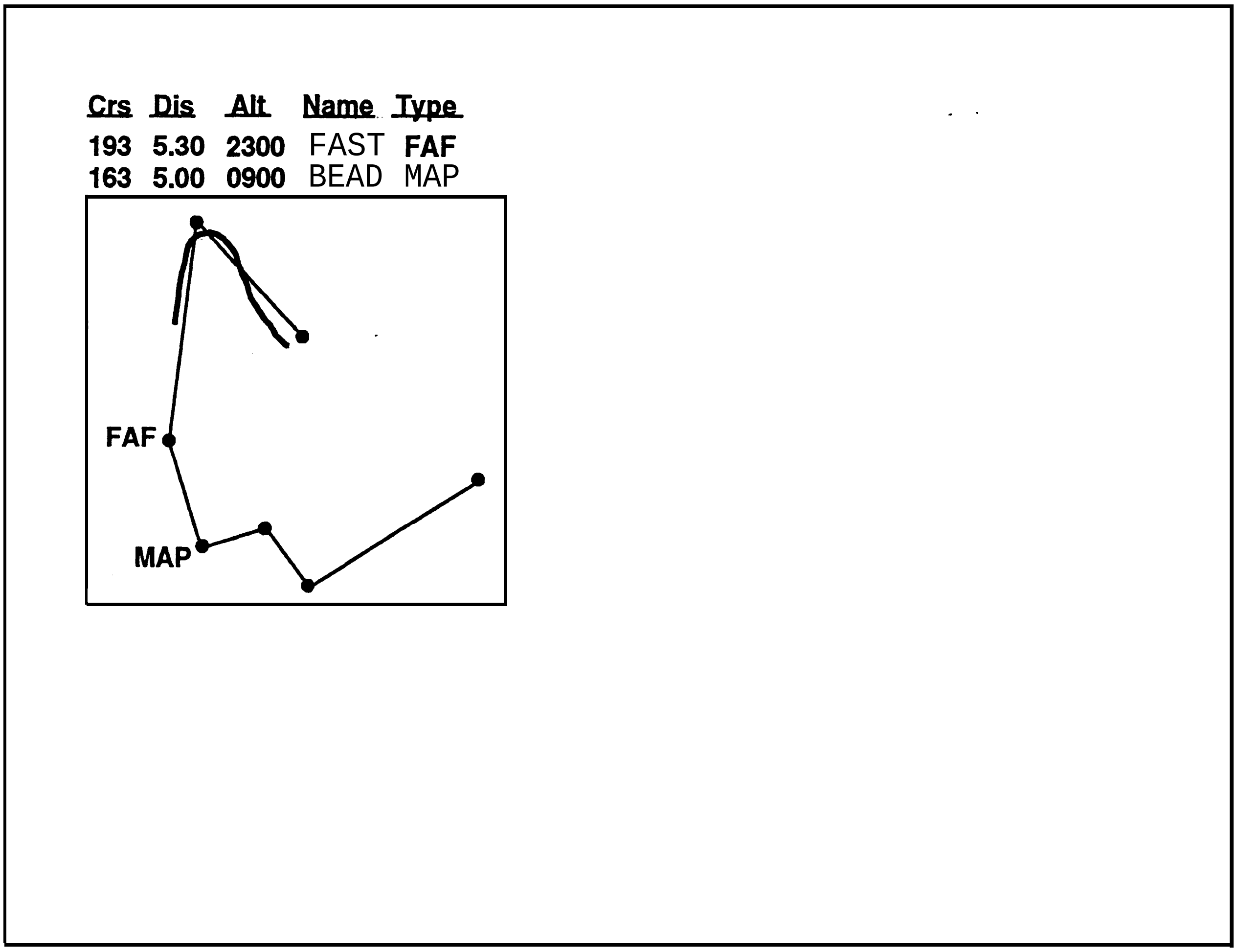


Figure 8. Hybrid Map and Tabular Format. Plan view map with schematic of approach course, minimal text, and flight track. Two lines of text provide information for current waypoint and next waypoint.

The display in Figure 8 was designed to test specific issues in electronic chart development. First, the size of the map has been adjusted so that the utility of small map displays can be assessed. With the removal of much of the text from the map, there is also an issue of the interpretation of information that has been divided between the plan-view map and the table. It may be concluded that minimal text on the map display is necessary for maintaining situation awareness. It is anticipated that the small size of the map will also discourage pilots from attempting to use the map for course guidance. Remaining issues to be resolved are the incorporation of extra information such as minima, notes, runway maps, and runway lighting systems. These limitations, however, do not detract from the basic concept of this design.



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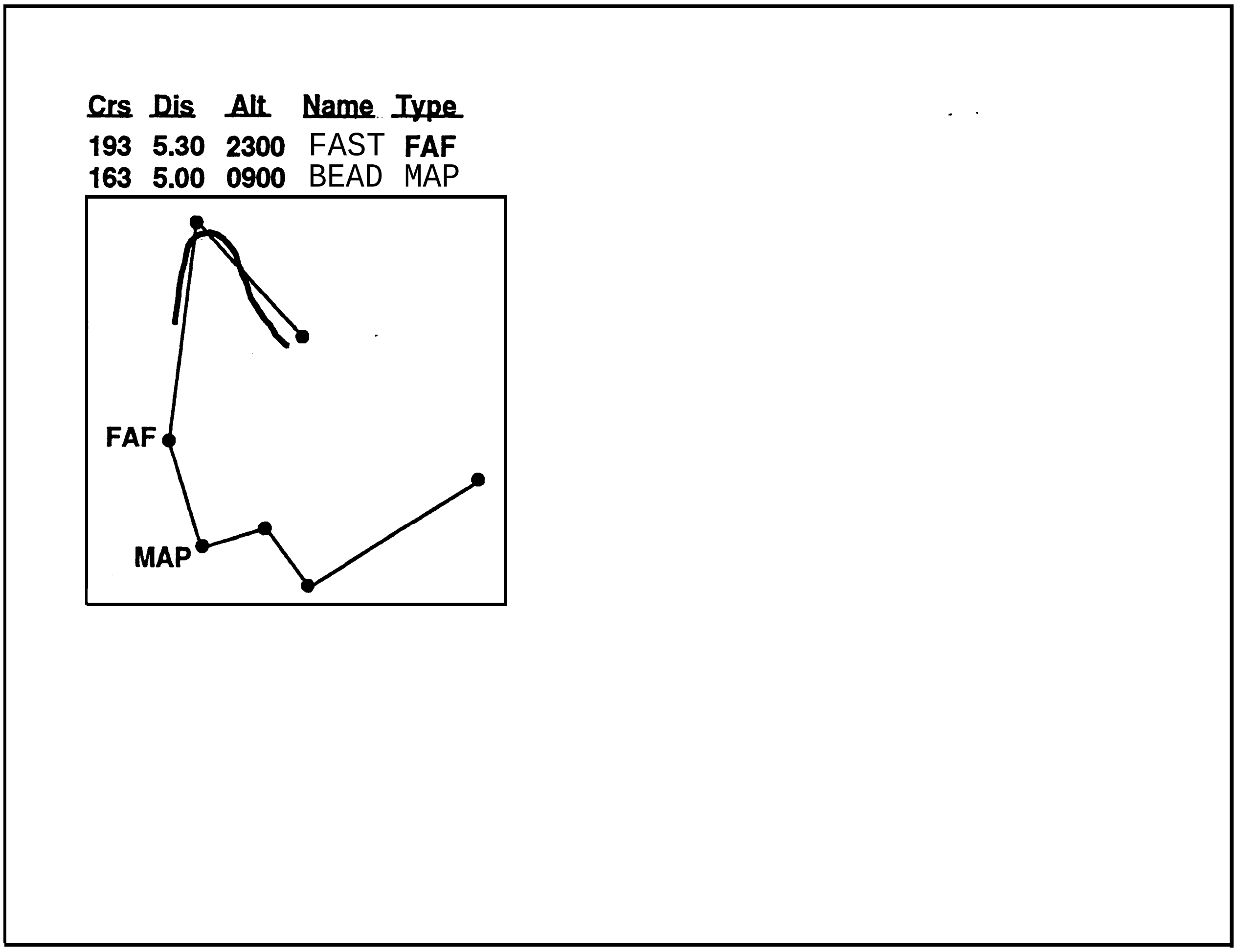

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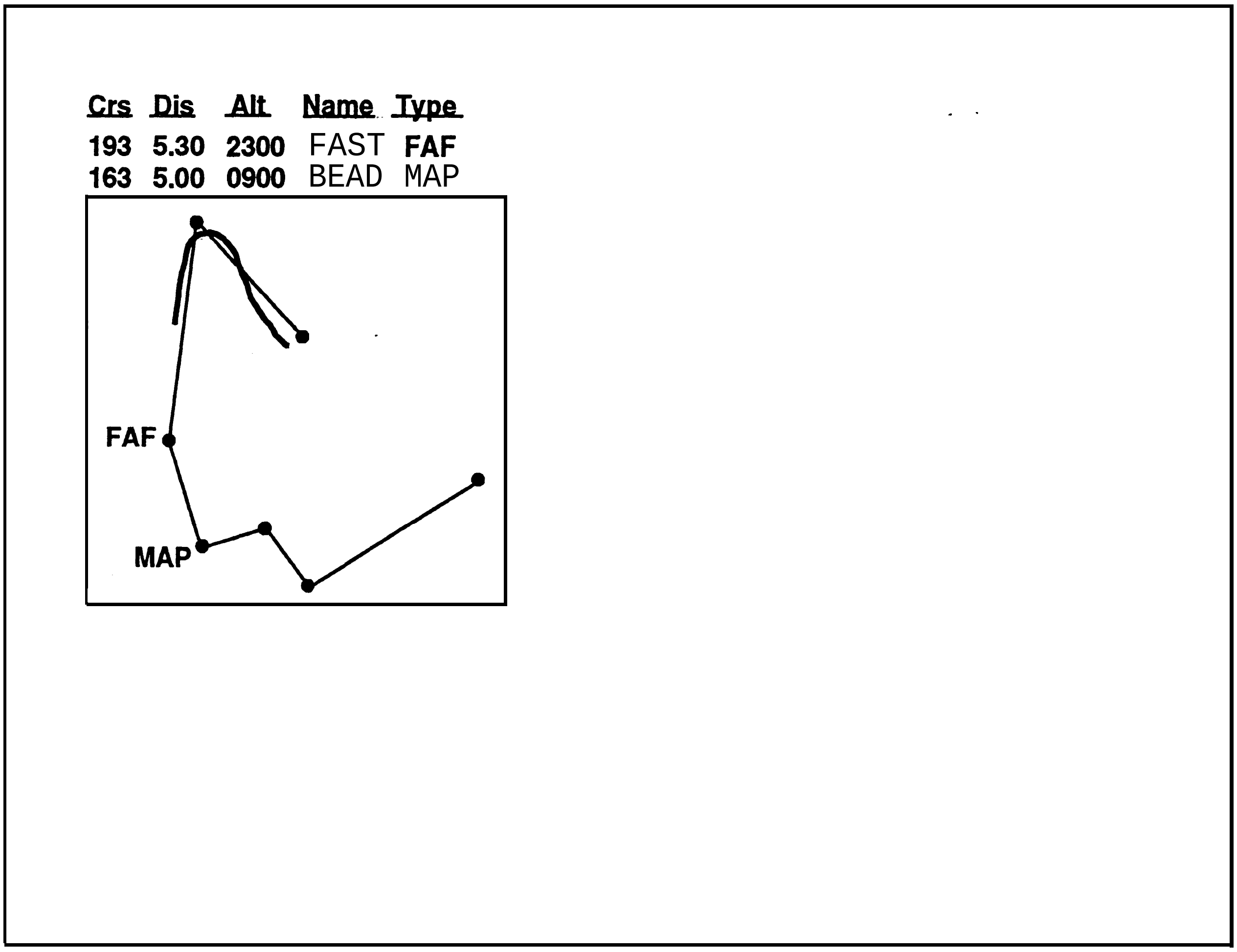

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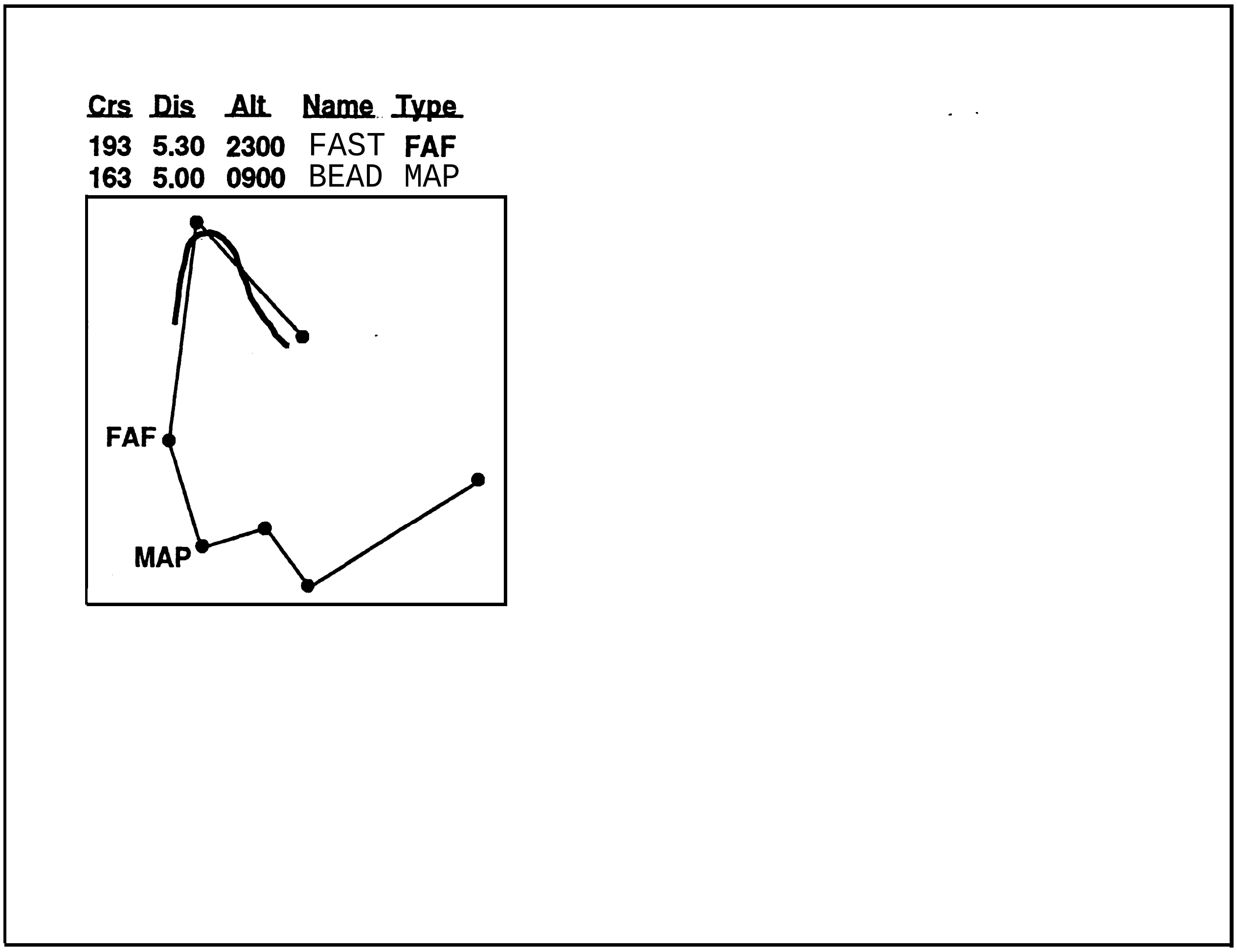

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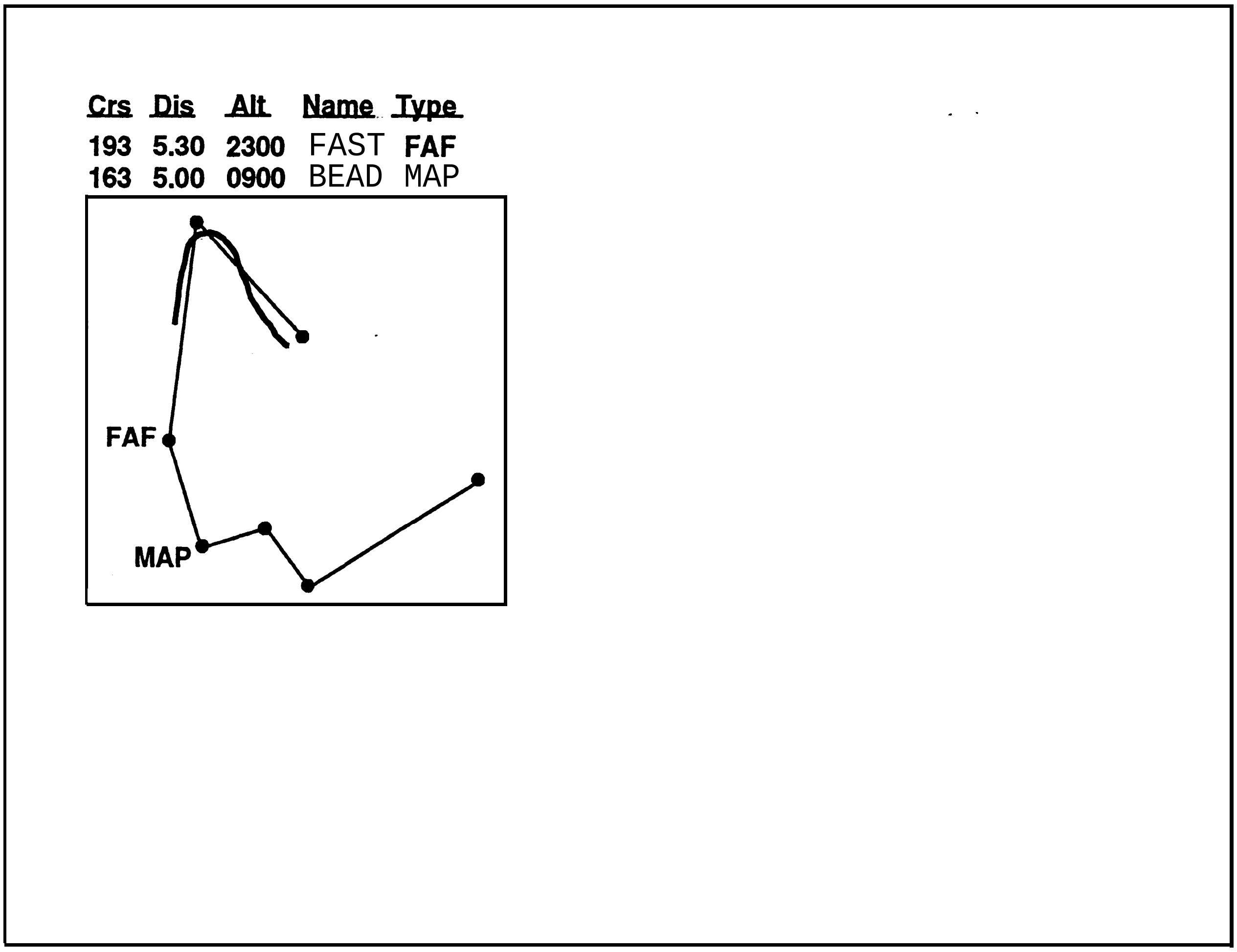

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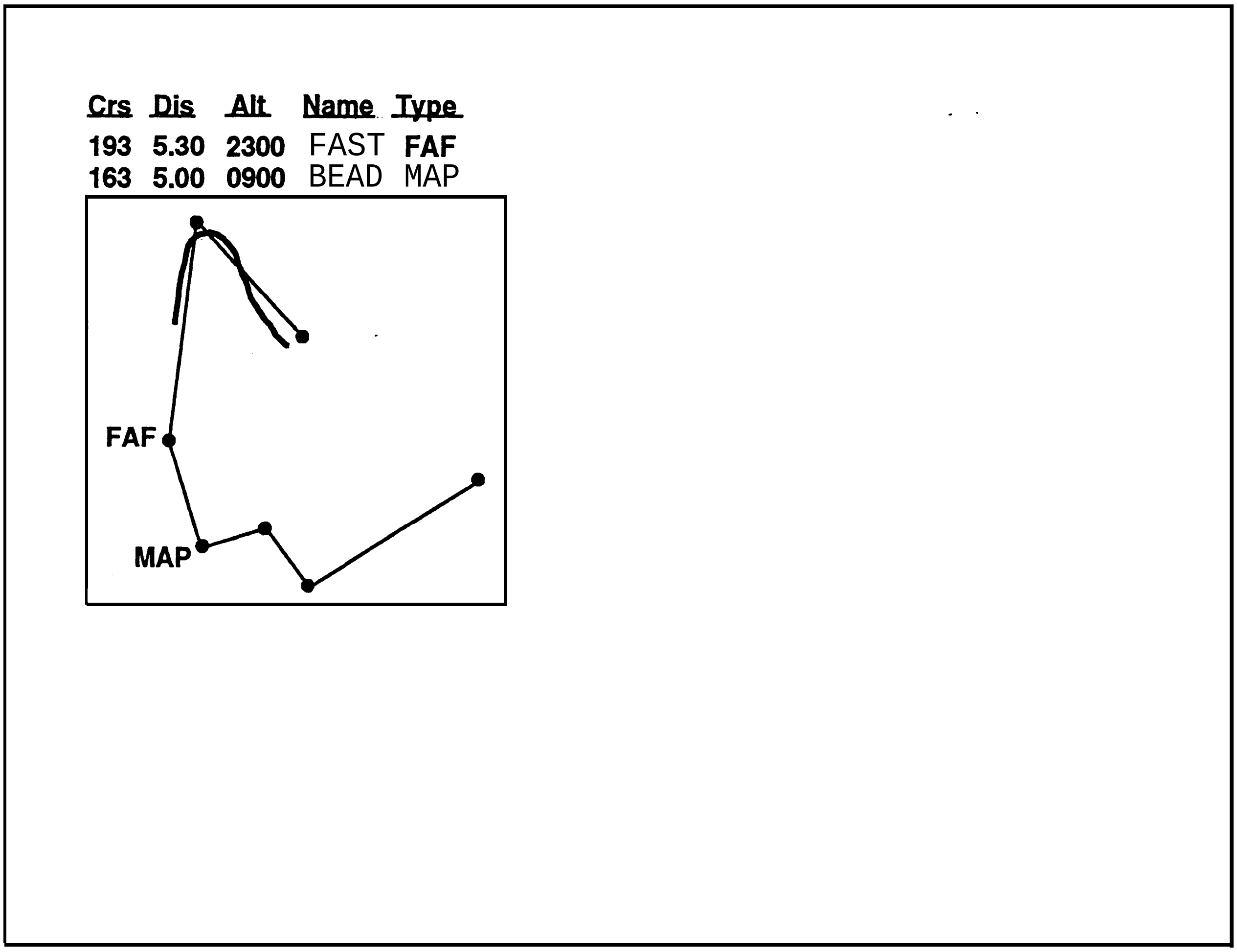

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APPENDIX B

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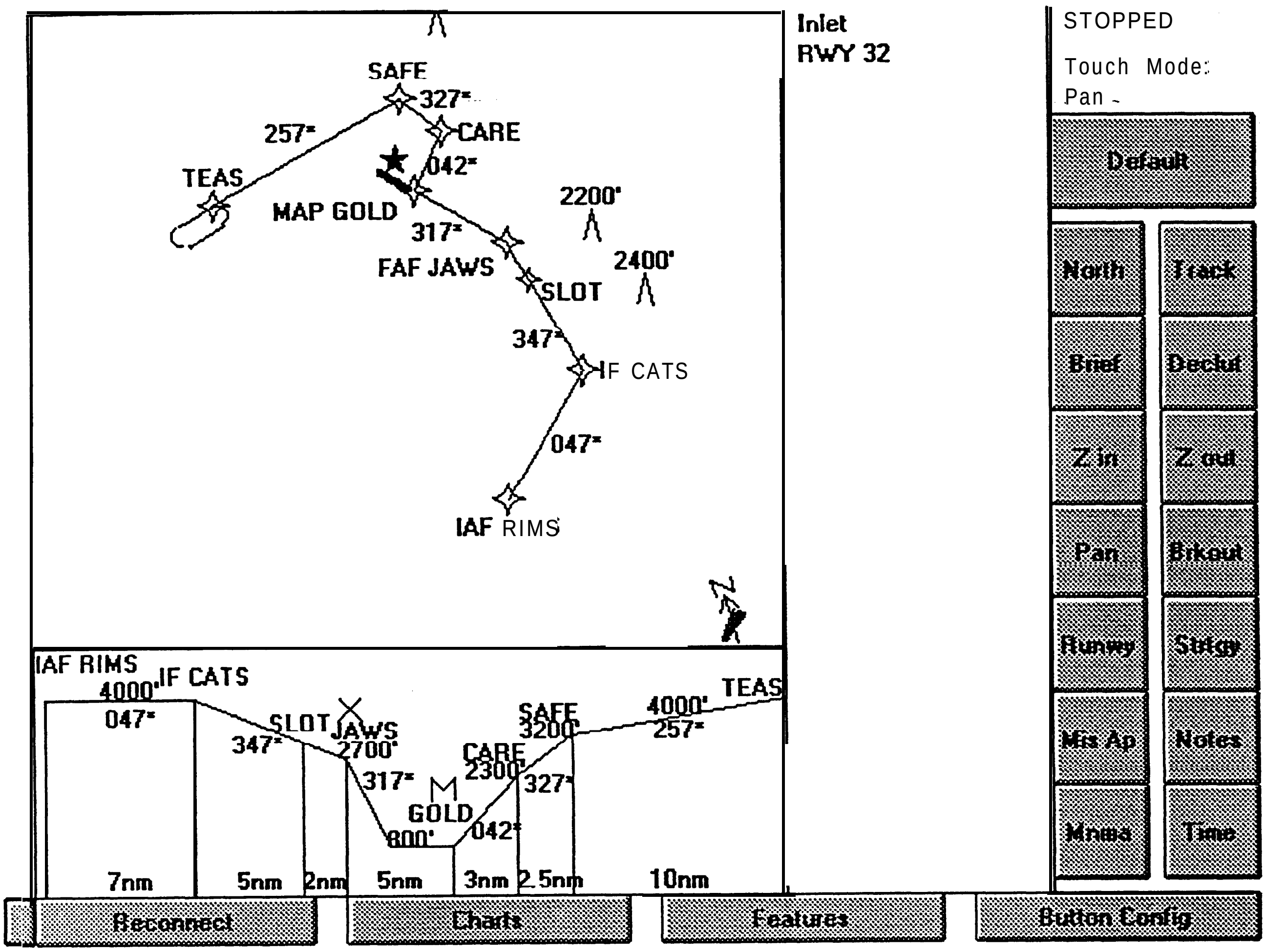

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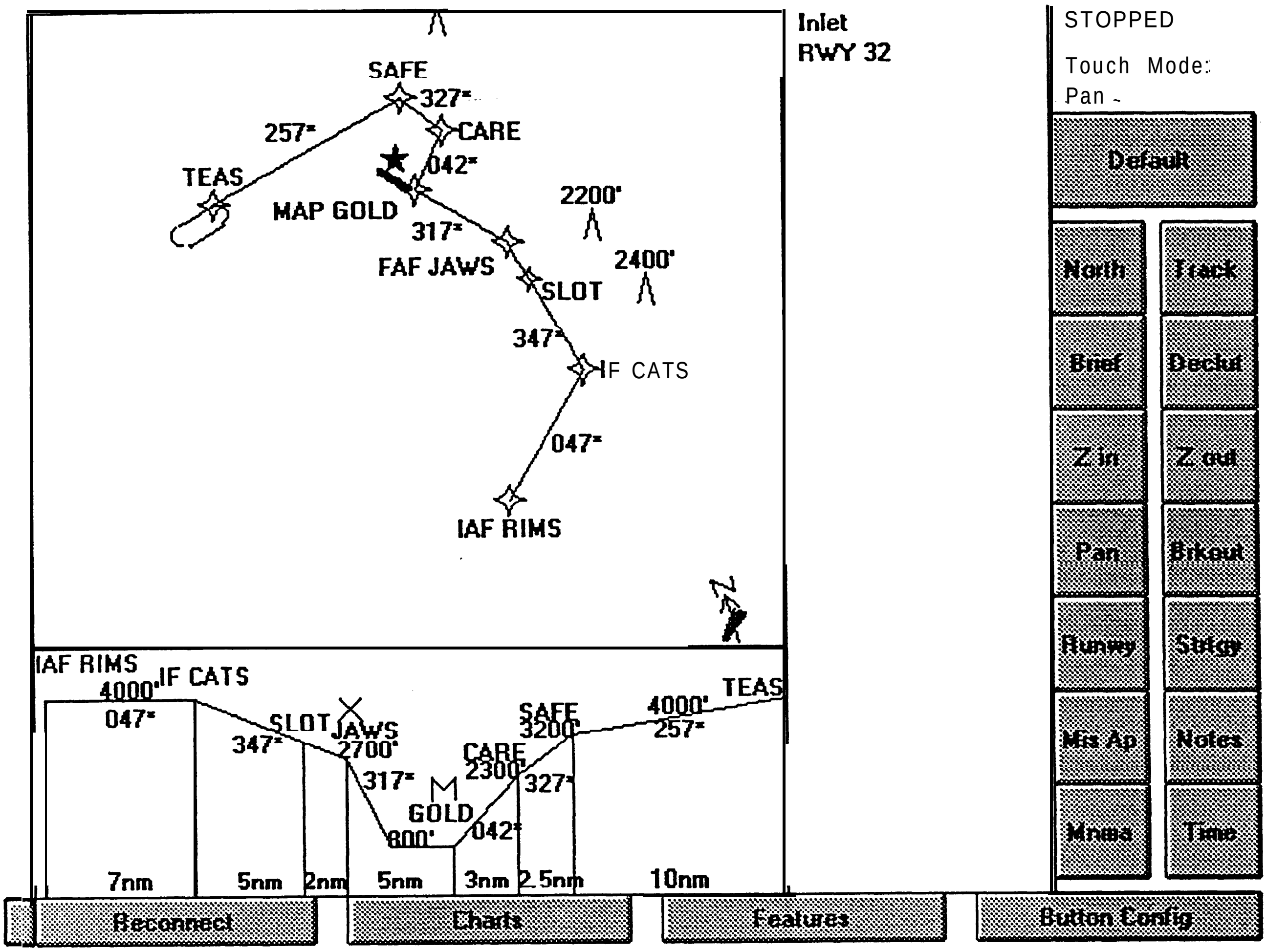

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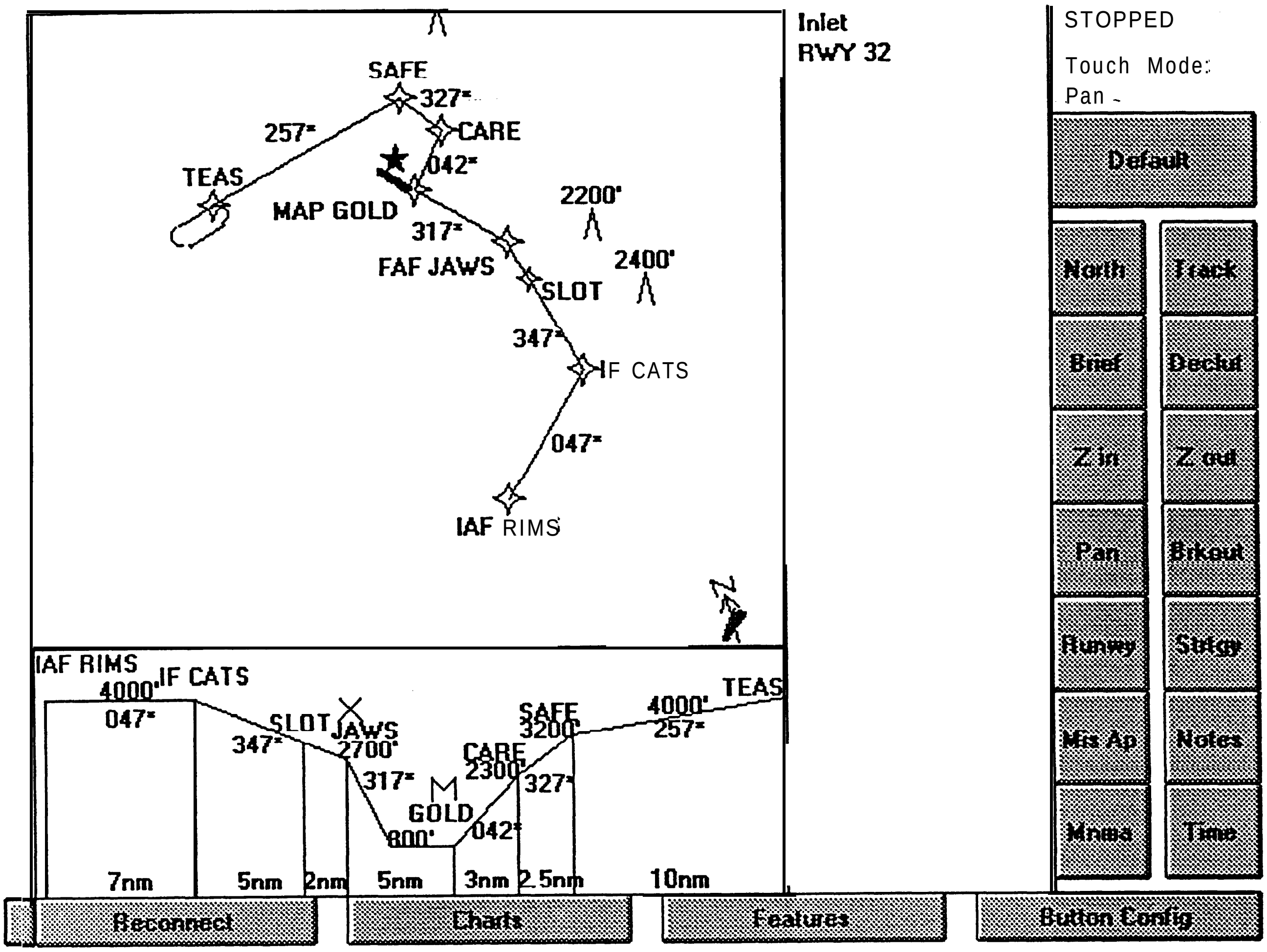

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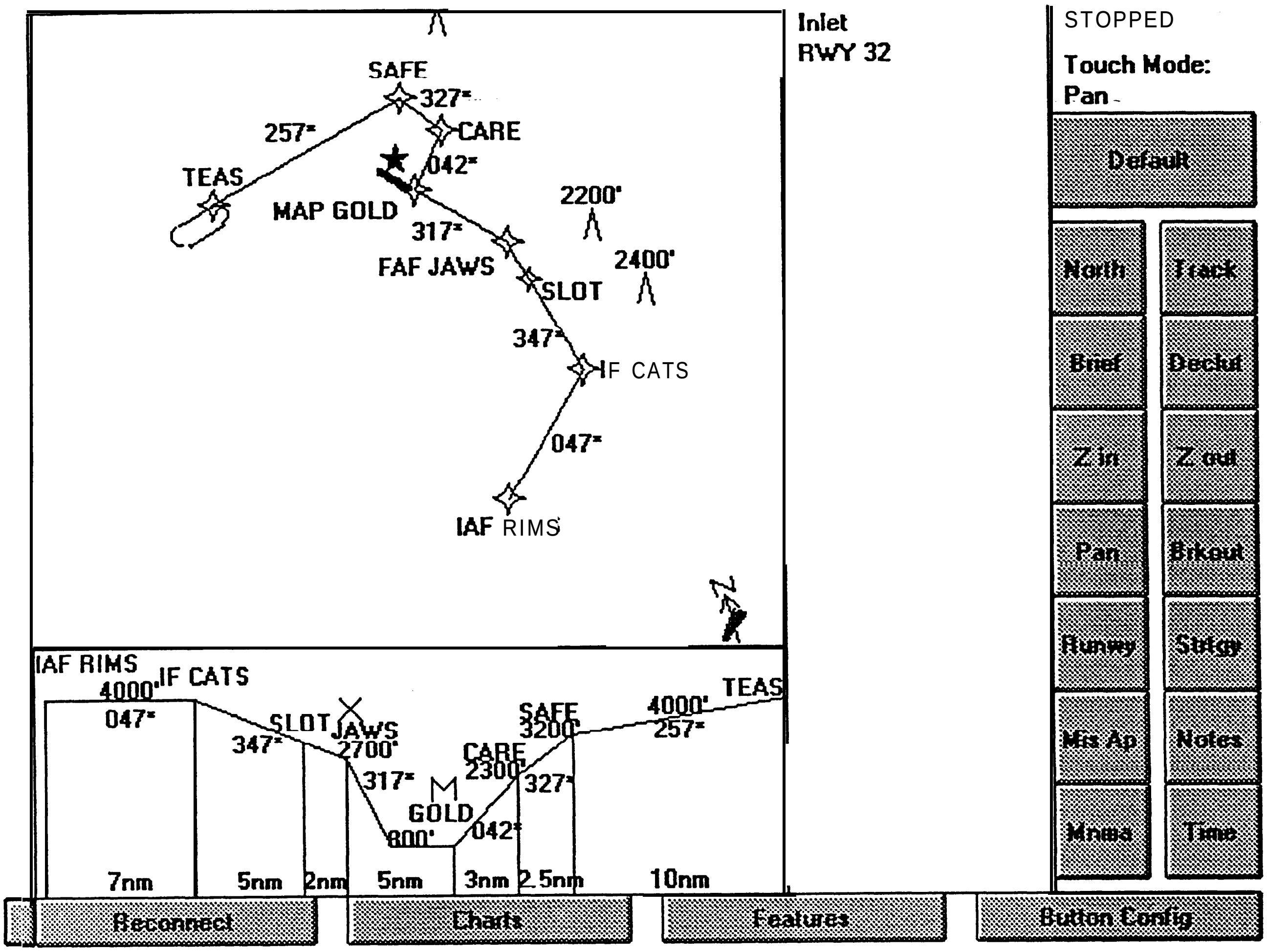

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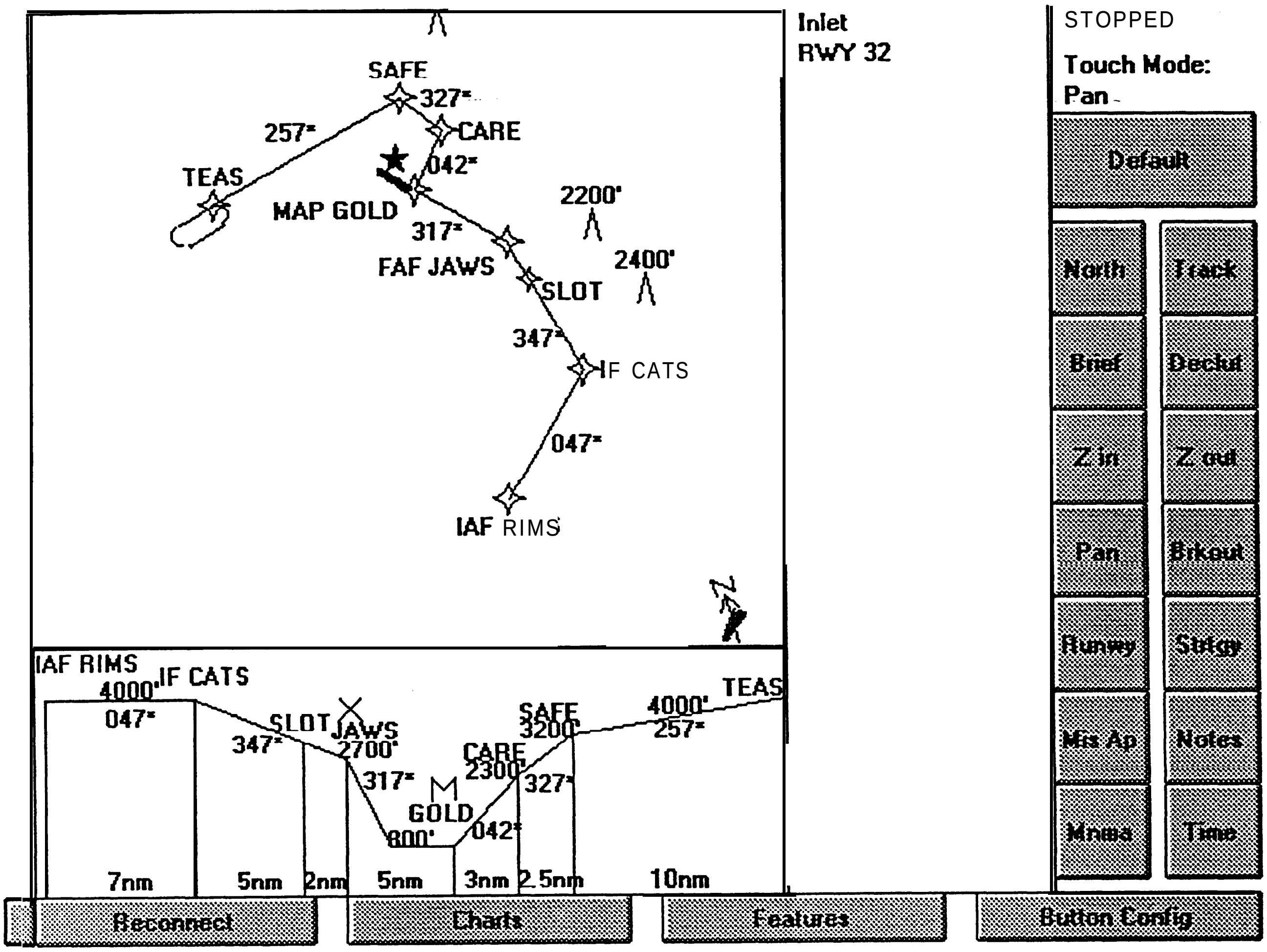

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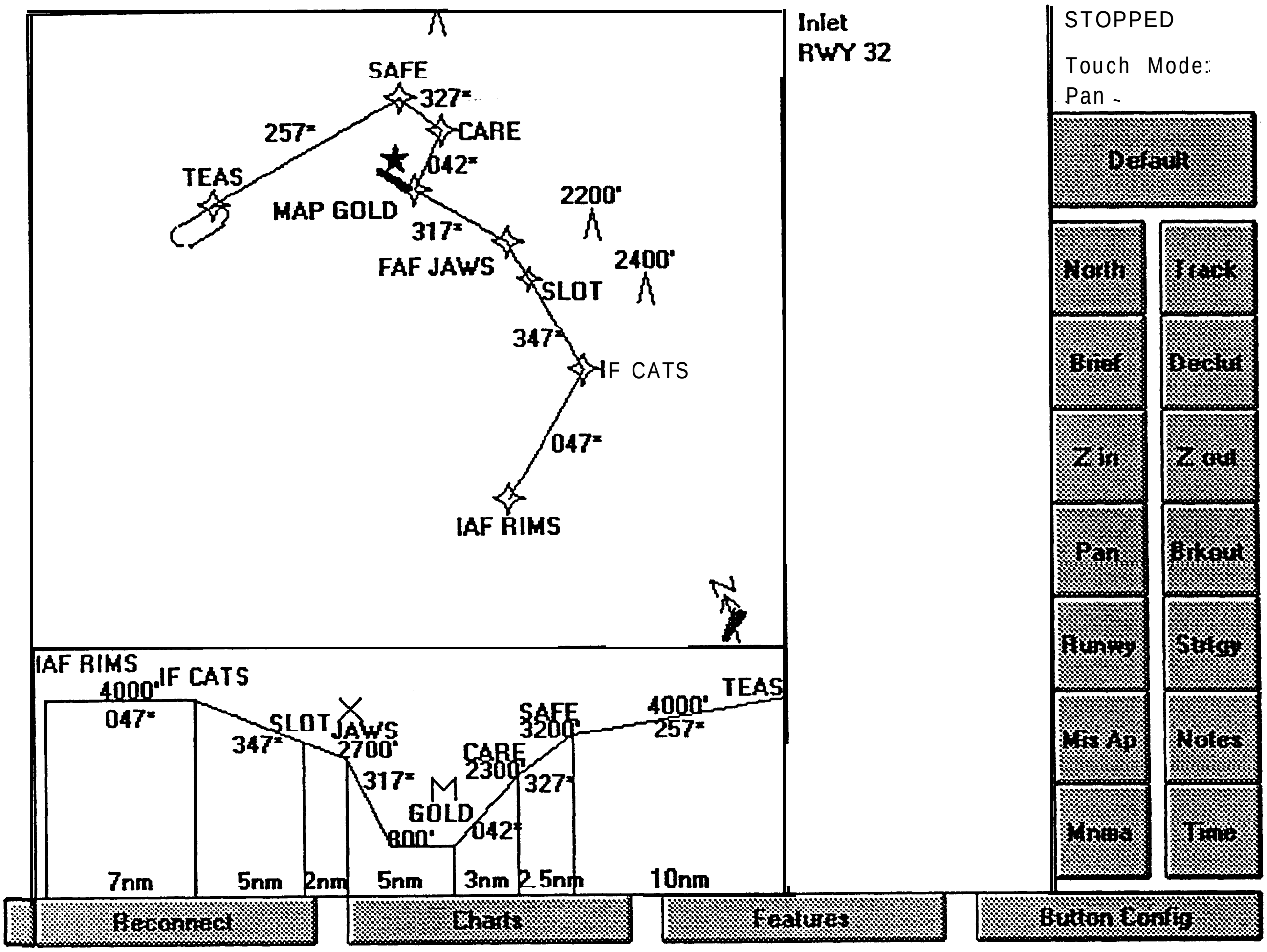

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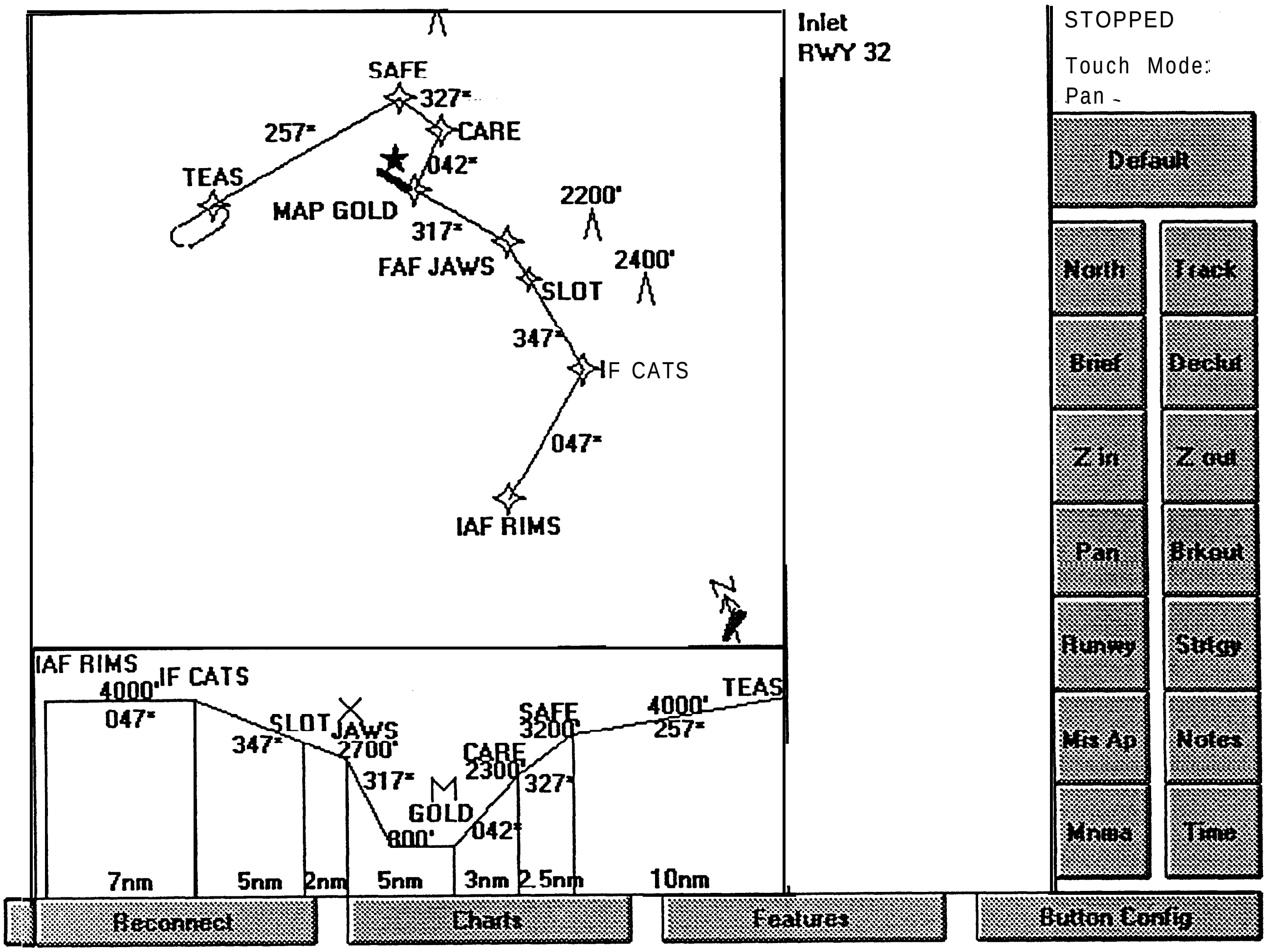

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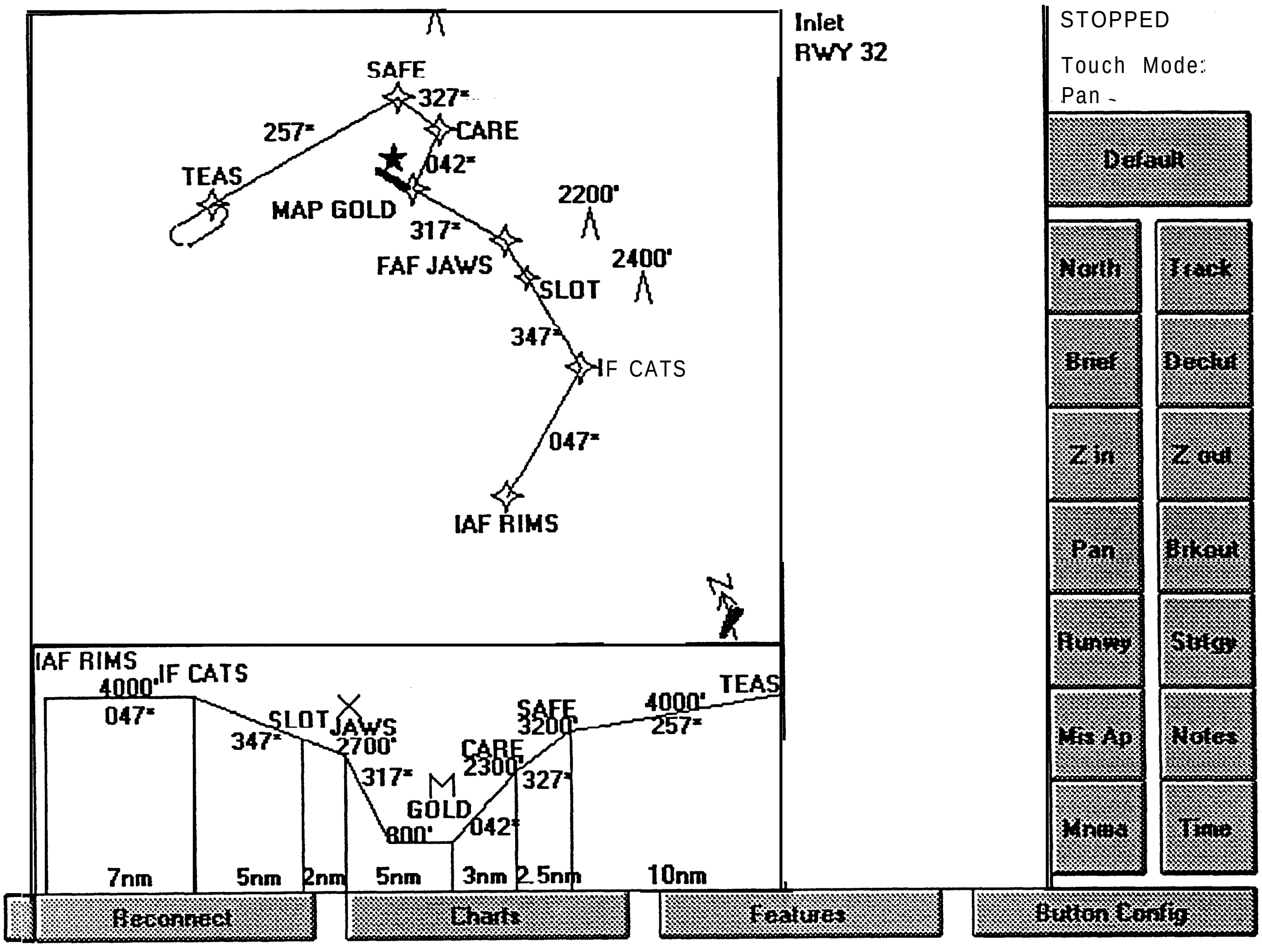

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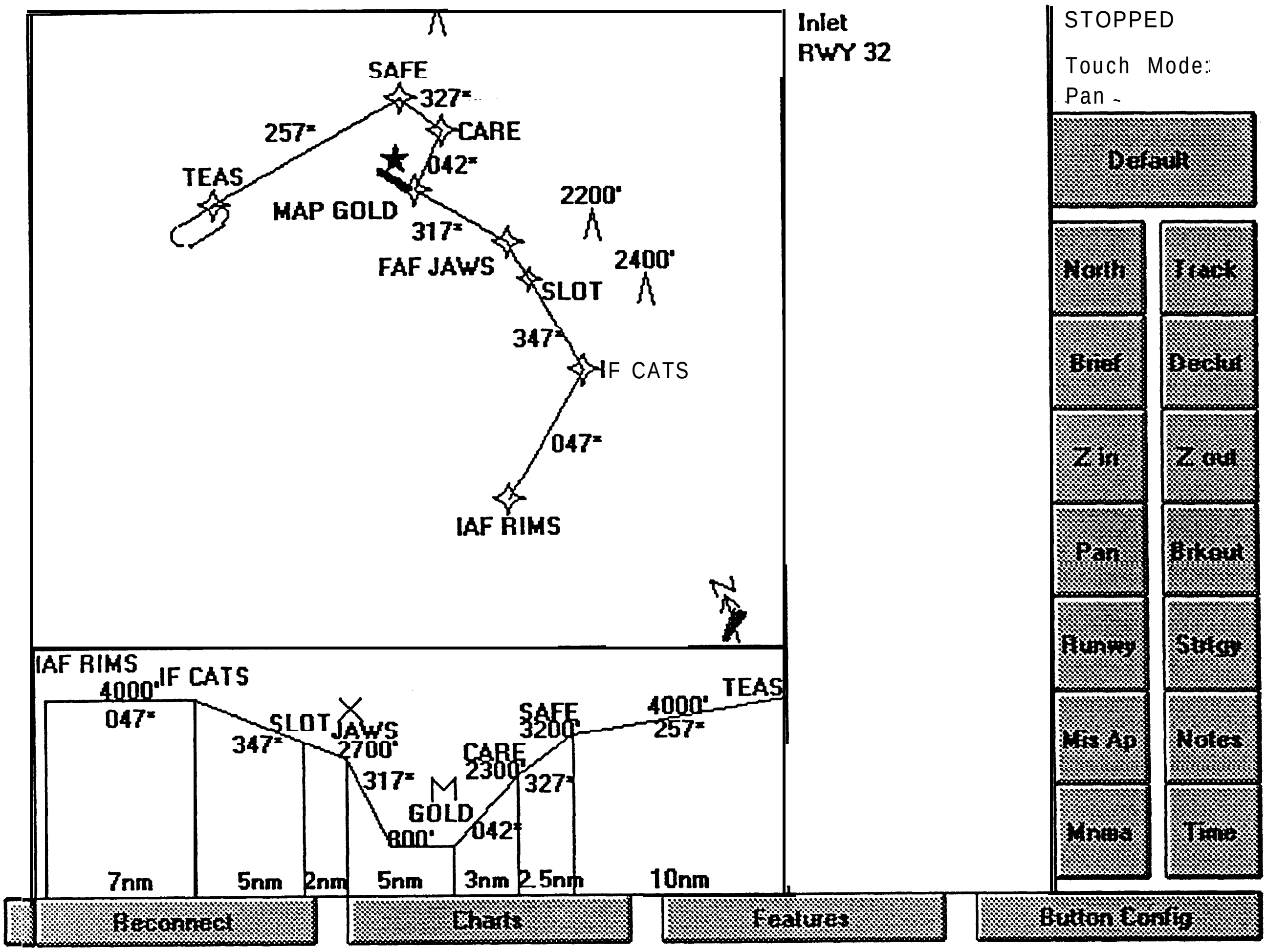

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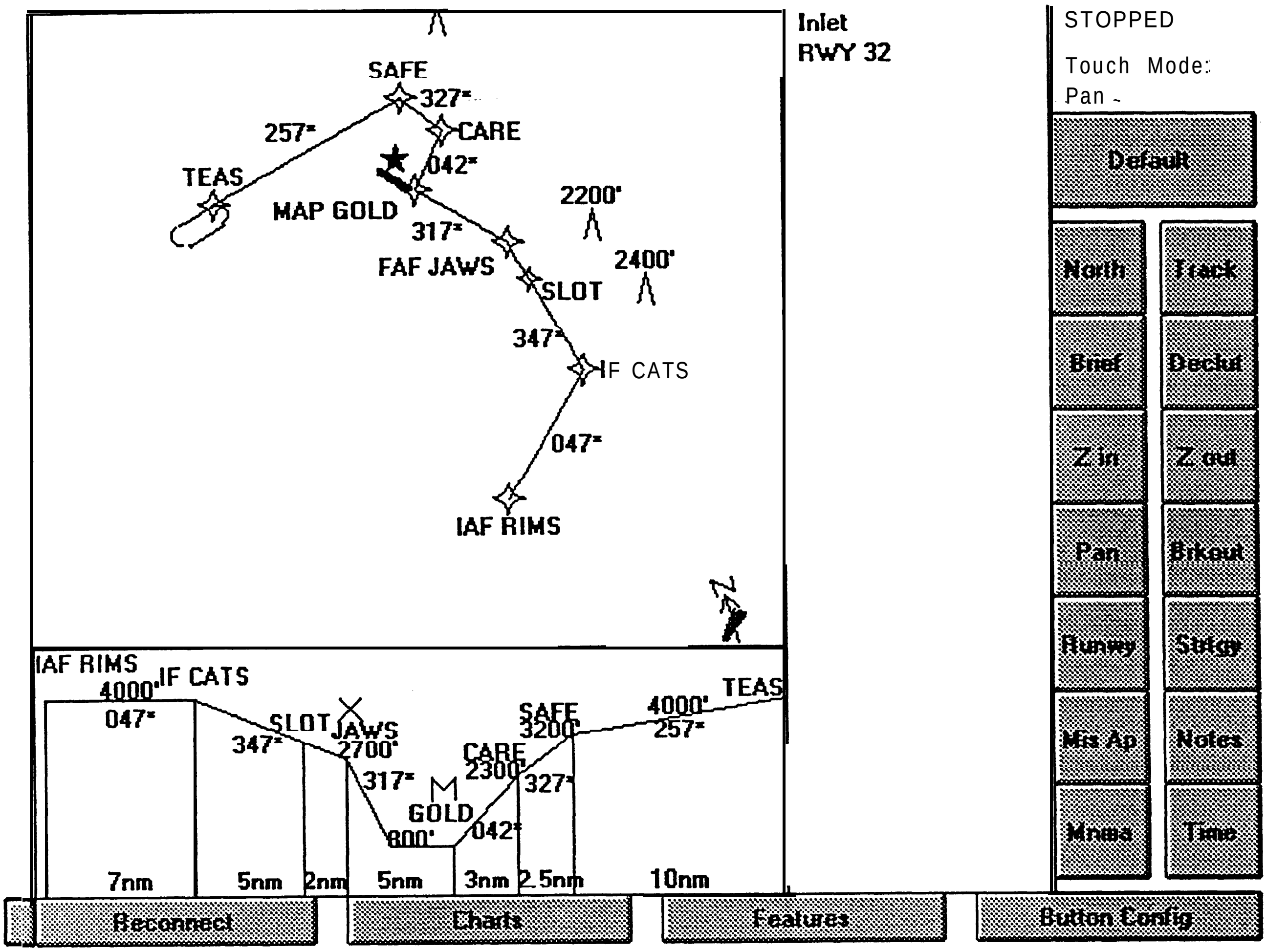

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